Materials for Advanced Packaging

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National Transportation Research Center

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Overview

Timeline

- Start – FY16
- End – FY18
- 50% complete

Budget

- Total project funding
  DOE share – 100%
- Funding received in FY16: $57k
- Funding for FY17: $171k

Any proposed future work is subject to change based on funding levels

Barriers

- Reduce cost of electric drive technology with 1.4 kW/kg, 4 kW/l, and 94% efficiency characteristics
- Reliability and lifetime of power electronic (PE) modules degrade rapidly with increased temperature
- Heat transfer in contemporary PE modules are often material-limiting

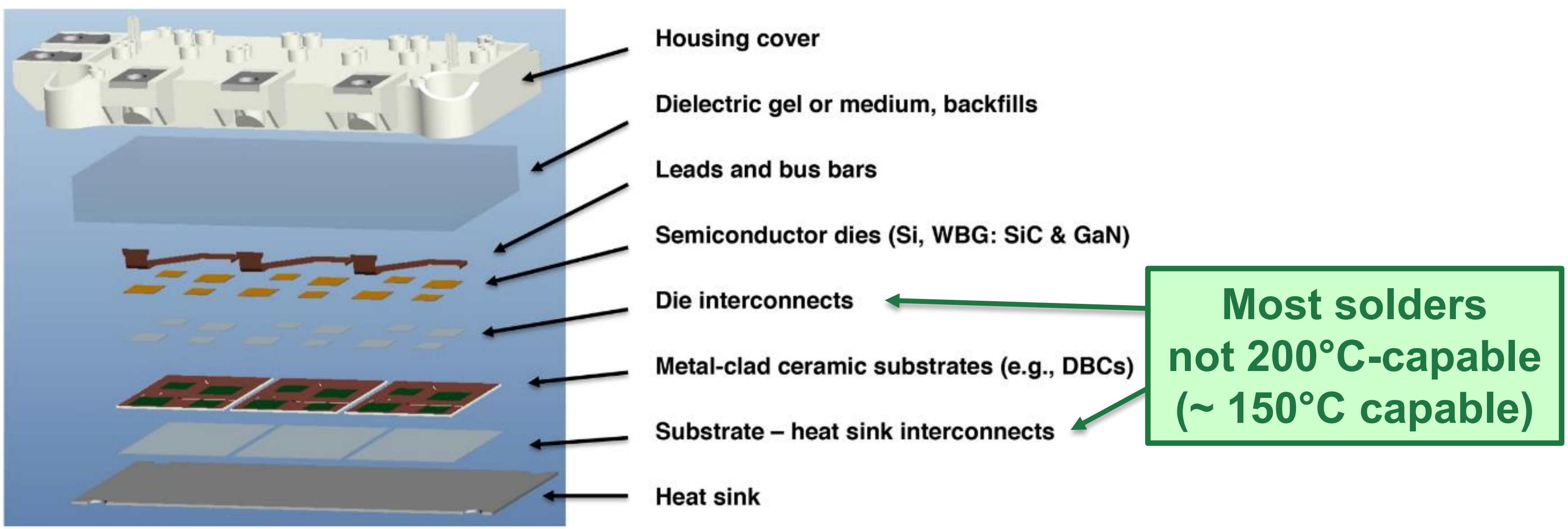
Partners

- Alfred University
- General Metal Finishing
- Henkel
- Heraeus
- Mount Union University
- NREL
- ORNL: Burress, Chen, Chinthavali, Modugno, Ozpineci, Wang, Waters, and Wiles
- Rogers Corporation
- UHV Sputtering

Project Objective and Relevance

- **Objective: advance sintered-silver (Ag) interconnect technology to enable a 200°C-capable, low-cost, and reliable electronic package with at least 15-year-life**
- **Relevance: contemporary PE devices cannot operate at 200°C because most conventional interconnect materials (solders) are in non-equilibrium above 150°C**

Example of a single-sided power electronic device



Milestones

Date	Milestones and Go/No-Go Decisions	Status
2016	<u>Milestone</u>: Fabricate sufficient numbers of shear test specimens to judge potential of new contact-drying method for printed Ag paste	Completed
2016	<u>Go/No-Go decision</u>: Shear strength > 10 MPa achieved?	Go
Aug 2017	<u>Milestone</u>: Fabricate sufficient numbers of test specimens to judge shear strength of reflow-oven-processed sintered-Ag interconnects	On schedule
Aug 2017	<u>Go/No-Go decision</u>: Shear strength > 10 MPa achieved?	On schedule

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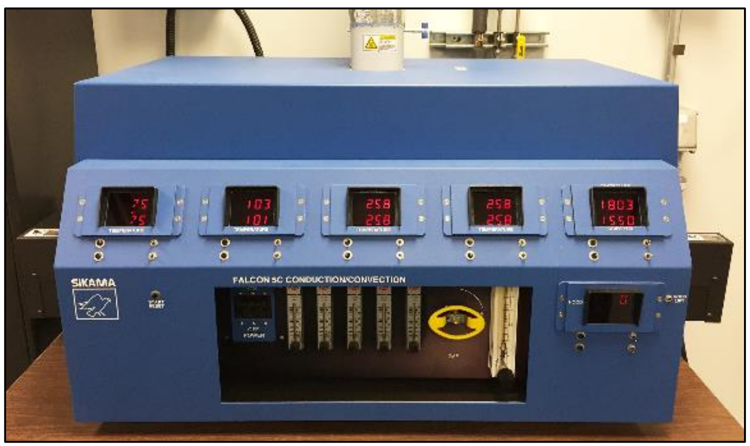
Approach/Strategy

- **Advance the processing and mechanical reliability of sintered-Ag for power electronic devices**
- **Promote 200°C device operation**
- **Promote the use of common reflow oven technology for pressureless Ag-sintering of interconnects**

ORNL Reflow Oven Used for Ag-Sintering Trials



Sintered-Ag Specimens Going into Reflow Oven

Any proposed future work is subject to change based on funding levels

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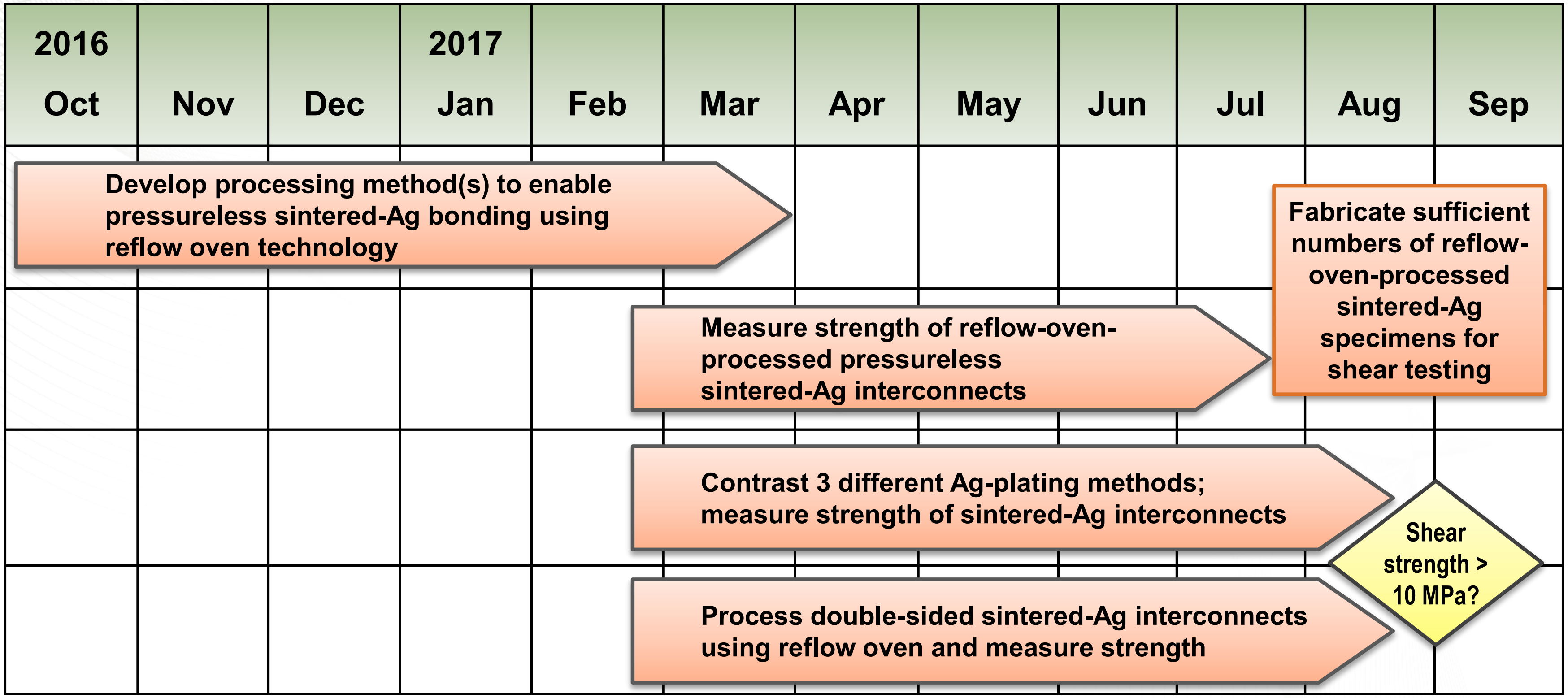
Approach FY17 Timeline



Go No/Go Decision Point: **Demonstrate shear strength > 10 MPa for reflow-oven-processed, pressureless sintered-Ag interconnects. (31 August 2017)**

Key Deliverable: **Fabricate sufficient numbers of reflow-oven-processed sintered-Ag specimens for shear testing. (31 August 2017)**

Any proposed future work is subject to change based on funding levels

Technical Accomplishments: Overview

1. Contact drying of printed sinterable-Ag paste
2. Tension/shear via cantilever loading
3. Apparent fracture toughness

} New Test Methods

Disseminate results & interpretations to open literature

Contact Drying of Printed Sinterable-Silver Paste[a]

Andrew A. Wereszczak,[b] *Senior Member IEEE*, Max C. Modugno,[c] Branndon R. Chen,[d] and William M. Carty[e]

Accepted

IEEE Transactions on Components, Packaging and Manufacturing Technology

Apparent Fracture Toughness of Pressureless Sintered Silver Interconnects

Andrew A. Wereszczak, *Senior Member, IEEE*, Max C. Modugno, and Branndon R. Chen

In Review

Failure Response of Sintered-Silver Interconnects via Cantilever Testing

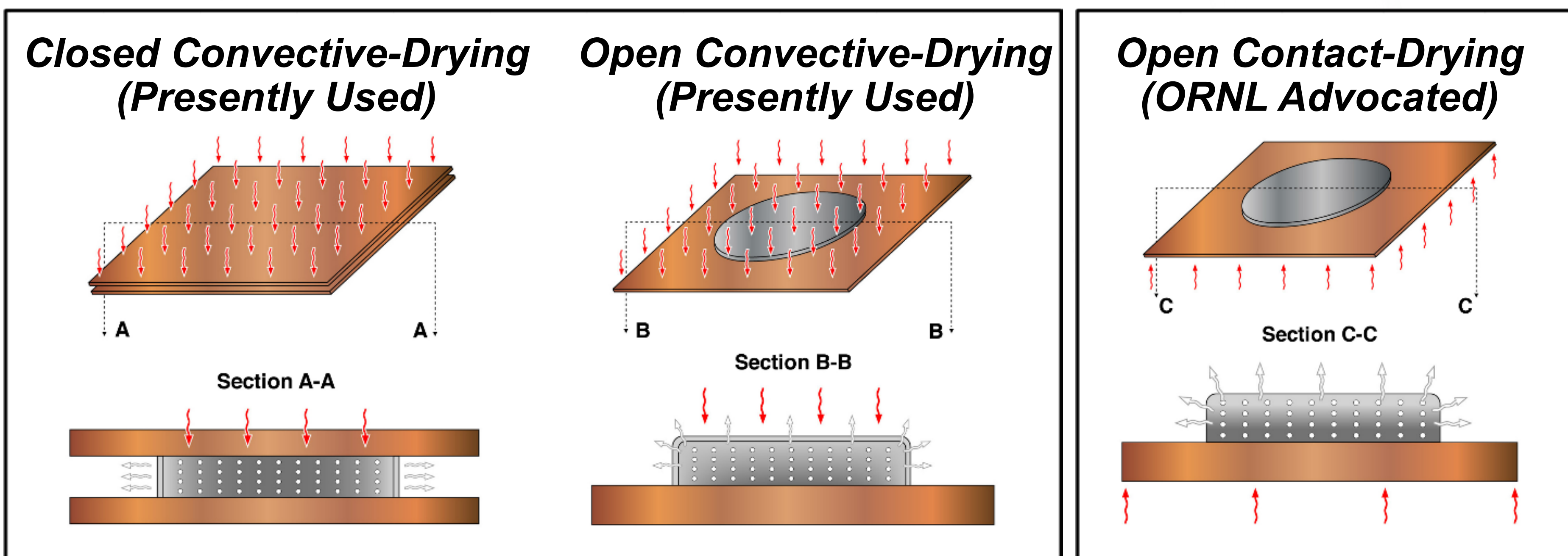
Andrew A. Wereszczak, *Senior Member, IEEE*, Branndon R. Chen, Osama M. Jadaan, Max C. Modugno, Jeffrey W. Sharp, and James R. Salvador

In Review

Technical Accomplishments: FY16-17 (1 of 6)

Contact Drying of Printed Sinterable-Ag Paste: Background

- **Drying of printed sinterable-Ag paste is a crucial pre-sintering step yet taken-for-granted and overlooked**
- **Vendor-advocated convective drying methods are limiting**
- **Contact-drying is an enabler**
- **Conceived from previous research**

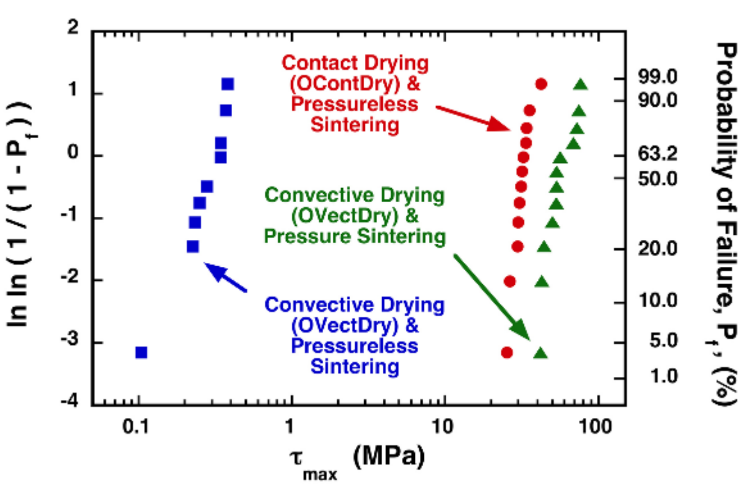


Technical Accomplishments: FY16-17 (2 of 6)

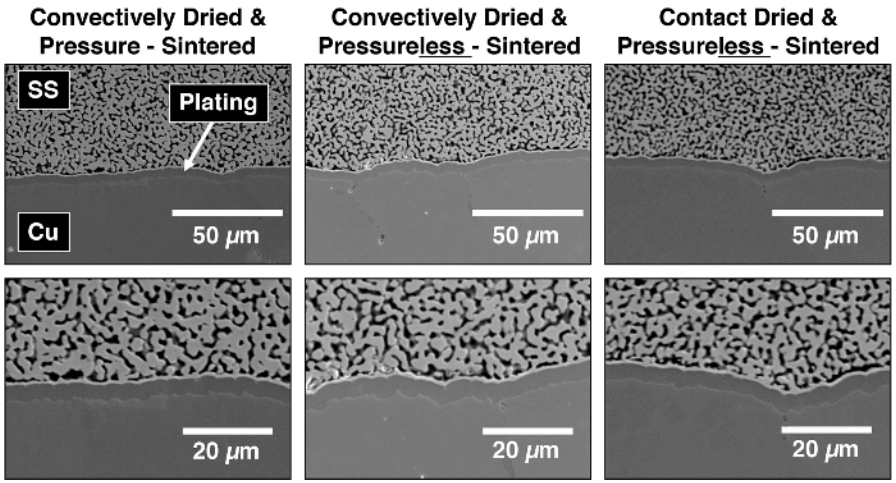
Contact Drying of Printed Sinterable-Ag Paste: Conclusions

- **Contact drying enables the use of pressureless sintering, large area bonding, and reflow-oven processing**
- **Contact drying with pressureless sintered-Ag can produce good shear strengths and equivalent microstructures to those of pressure-assisted sintering**

Good Strength



Equivalent Microstructures

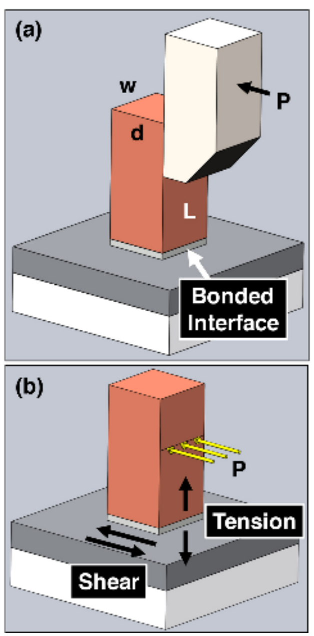


Technical Accomplishments: FY16-17 (3 of 6)

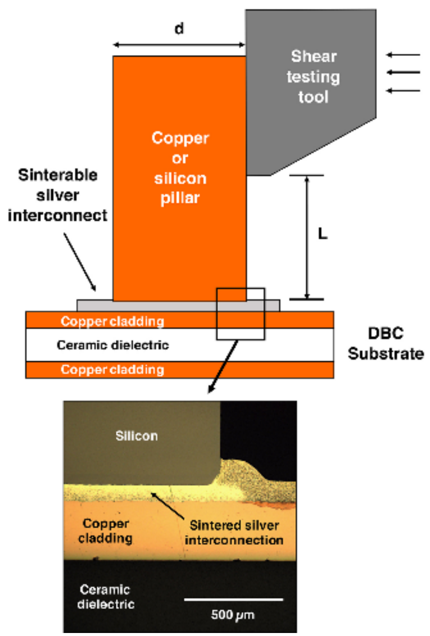
Tension/Shear Failure In Interconnects via Cantilever Loading: Background

- **Cantilever testing benefits the understanding of how interconnects (e.g., sintered-Ag) mechanically respond**
- **Superimposes tension (primary) and shear**
- **Deep beam theory needed for correcting analysis**

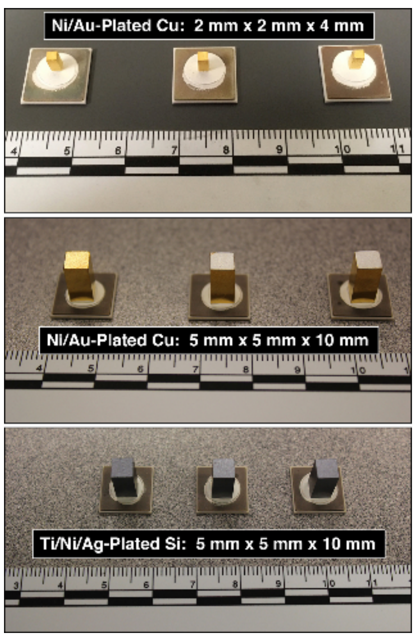
Loading Schematic



Interconnect Loading



Test Specimens

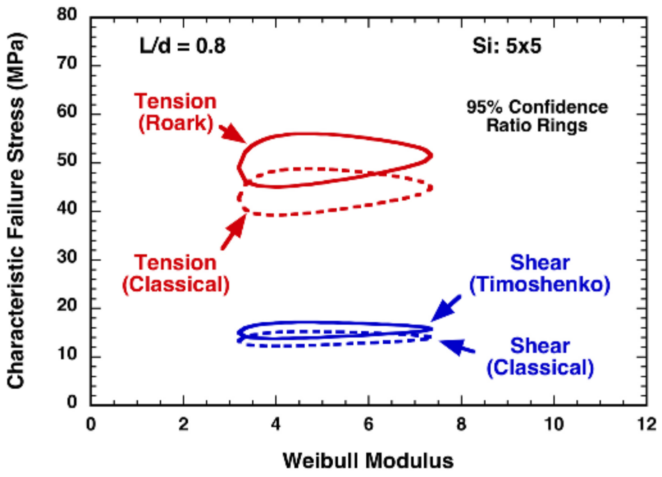


Technical Accomplishments: FY16-17 (4 of 6)

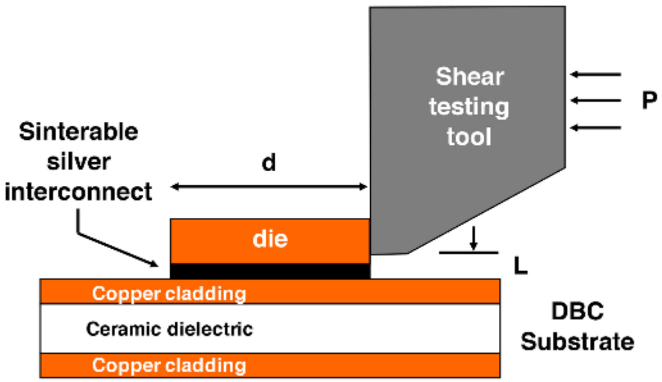
Tension/Shear Failure In Interconnects via Cantilever Loading: Conclusions

- **Ti/Ni/Ag plating on silicon, bonded to sintered-Ag, resulted in very strong interconnects**
- **Cantilever testing enables effective mechanical evaluation of interconnects (solders, sintered-Ag, etc.)**

Corrected Results from Deep Beam Theory



Die Test Applicability

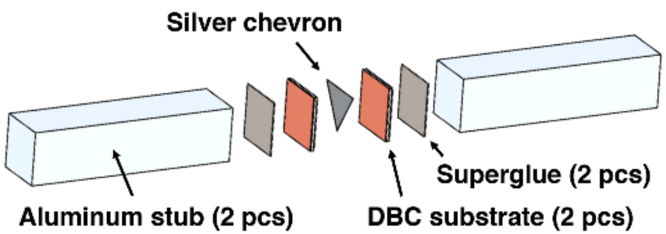


Technical Accomplishments: FY17 (5 of 6)

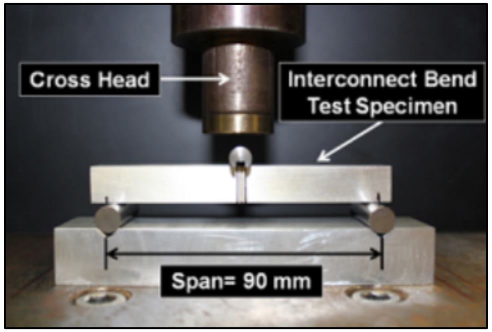
Apparent Fracture Toughness of Interconnects: Background

- **Susceptibility to crack growth or delamination in interconnects is related to fracture toughness (K_{Ic})**
- **Interconnect testing adapted from ASTM K_{Ic} test methods**
- **K_{Ic} is a useful complement to interconnect shear strength, tensile strength, and is associate with fatigue response**

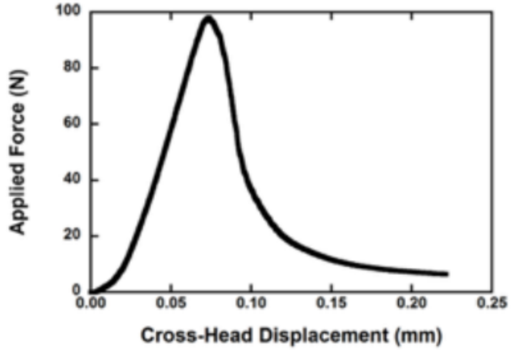
Schematic of Interconnect Bend Test Specimen (IBTS)



3-Point Bending of IBTS



Integrated Area Related to K_{Ic}



Technical Accomplishments: FY17 (6 of 6)

Apparent Fracture Toughness of Interconnects: Conclusions

- **The Ag-plating/sintered-Ag combo needs improvement**
- **K_{Ic} (interconnect sintered-Ag) < K_{Ic} (bulk sintered-Ag)**
- **Apparent first documentation of K_{Ic} of sintered-Ag**

Apparent Fracture Toughness (K_{Ic}) Comparisons

Interconnect Material	Apparent Fracture Toughness (MPa√m)
Bulk Sintered Silver (this work)	2.3 - 2.4
Sintered-Silver Interconnect with Electroless Ag Plating (this work)	1.5 ± 0.2
Various Solders (work of others)	1 - 11

Responses to Previous Year Reviewers' Comments

Project started after 2016 Annual Merit Review

Collaboration and Coordination with Other Institutions

- ***Alfred University***: Alternative sinterable-Ag processing
- ***Mount Union University***: Mechanical test development for interconnects
- ***National Renewable Energy Laboratory (NREL)***: Materials for electric motors (Bennion and Cousineau)
- ***General Metal Finishing***: Metal plater
- ***Henkel***: Sinterable-Ag manufacturer
- ***Heraeus***: Sinterable-Ag manufacturer
- ***Rogers Corporation***: DBC substrate manufacturer and plating studies
- ***UHV Sputtering***: Metal plater

Remaining Challenges and Barriers

- **Identifying the most practical, reliable, and economical Ag (or other metal) plating choice for use with sintered-Ag interconnects**
- **Identifying conditions to avoid onset of delamination**

Any proposed future work is subject to change based on funding levels

Proposed Future Work

- **Remainder of FY17**
  - **Reflow oven processing of sintered-Ag**
  - **Ag-plating study**
  - **Double-sided sintered-Ag study**
- **FY18**
  - **Process thick films directly on heat exchangers**
  - **Process sintered-Ag with thick film technology**

Any proposed future work is subject to change based on funding levels

Summary

- <u>Relevance:</u>
  - Higher-temperature-capable materials, improved thermal transfer, reliability, and efficiency
  - Addresses major materials needs for the EV/HEV sectors
- <u>Approach/Strategy</u>: 200C - capable interconnects
- <u>Collaborations:</u> Industry, university, and national laboratory
- <u>Accomplishments:</u>
  - Measured thermal conductivity anisotropy in copper windings
  - Developed contact drying method with sintered-Ag
  - Identified, tensile, shear, and fracture toughness responses of sintered-Ag interconnects
- <u>Future Work:</u>
  - Complete reflow oven, Ag-plating, and double-sided sintered-Ag processing studies
  - Combine thick-film and sintered-Ag technologies

Any proposed future work is subject to change based on funding levels